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Abstract

Combined ultrasound-guided blockade of the suprascapular and axillary nerves has been proposed as an alternative to interscalene blockade for pain control in shoulder joint pathology or post-surgical care. This technique could help avoid respiratory complications and/or almost total upper limb palsy. Nowadays, the axillary nerve blockade is mostly performed using an in-plane caudal-to-cephalic approach from the posterior surface of the shoulder, reaching the nerve immediately after it exits the neurovascular quadrangular space (part of the *spatium axillare*). Despite precluding most respiratory complications, this approach has not made post-surgical pain relief any better than an interscalene blockade, probably because articular branches of the axillary nerve are not blocked.

Cephalic to caudal Methylene Blue injections were placed in the first segment of the axillary nerve of six Thiel-embalmed cadavers using an ultrasound-guided anterior approach in order to compare the distribution with that produced by a posterior approach to the contralateral axillary nerve in the same cadaver. Another 21 formalin-fixed cadavers were bilaterally dissected to identify the articular branches of the axillary nerve.

We found a good spread of the dye on the axillary nerve and a constant relationship of this nerve with the *subscapularis* muscle. The dye reached the musculocutaneous nerve, which also contributes to shoulder joint innervation. We describe the anatomical landmarks for an ultrasonography-guided anterior axillary nerve blockade and hypothesize that this anterior approach will provide better pain control than the posterior approach owing to complete blocking of the joint nerve.

Introduction and aims

The axillary nerve (AN)

The source of the AN is the posterior cord of the brachial plexus (below the *pectoralis minor* muscle), from which it takes an inferolateral direction underlying the deep deltoid fascia and overlying the myotendinous lateral insertion of the subscapularis muscle (SSM). It reaches the inferolateral border of the SSM and enters the quadrangular space (quadrilateral space of Velpeau), at which point it shifts direction dorsally. At some point along its course it branches into anterior and posterior divisions that carry motor fibers for the *infraspinatus* and *teres* minor muscles as well as sensory fibers (Fig. 1) to the shoulder joint capsule and the skin. The pattern of branching and the distribution of the fibers differ markedly among individuals (Loukas *et al*., 2009; Apaydin *et al*., 2009; Davidson *et al.,* 2009).

The AN, deriving from the posterior cord, courses around the inferolateral margin of the SSM to enter the quadrangular space; in this area, it branches off to the SSM, the *teres major* and the anterior part of the shoulder joint capsule (Aszmann *et al.*, 1996; Tubbs *et al*., 2007; Uz *et al*., 2007; Stecco *et al*., 2010; Leschinger *et al*., 2017). The superior lateral brachial cutaneous nerve, motor branches to the *teres minor* muscle and some branches to the deltoid muscle can be blocked by a posterior blockade, but this will not necessarily reach all branches to the deltoid muscle or to the shoulder joint capsule (Checcucci *et al*., 2008; Dhir *et al*., 2016).

Innervation of the shoulder joint

According to Wrete (1949), the anterior aspect of the shoulder joint is innervated by branches derived from the AN (see also Aszmann *et al*., 1996), with contributions from the musculocutaneous (MCN), subscapular and suprascapular nerves (Fig. 1C). Another classical anatomical study (Niklaus Rüdinger: Die Gelenknerven des menschilchenKörpers, 1857; Ferdinand Enke, Erlangen), reviewed by the same author (1949), identifies AN articular branches arising very close to where the nerve emerges from the posterior cord of the brachial plexus, and some fibers that reach the capsular tissue after innervating the sheath of the tendon of the *biceps brachii*. The upper area of the anterior aspect, and the superior side of the shoulder joint, receive some innervation from the lateral pectoral nerve (see Eckmann *et al*., 2017). The posterior aspect of the shoulder joint is innervated by the suprascapular nerve (SSN) with an important contribution from the AN in its dorsal and caudal area. The estimated contribution of the AN to the totality of the shoulder joint innervation is variable. Near the quadrangular space, the main trunk gives direct articular branches to the inferior area (see also Tran *et al*., 2019) of the shoulder joint capsule, with other articular branches arising from the branch to the *teres minor* or appearing in the posterolateral aspect of the capsule after piercing the connective tissue of the tendon of the *biceps brachii* (Nasu *et al*., 2015; Eckmann *et al*., 2017). Some authors mention a single articular branch (Duparc *et al*., 1997), which they call the joint nerve (JN), while others use more general terms such as articular branch or capsular branch. The terms are used indifferently in the present study because it deals with the anatomical distribution and not the number of articular nerves.

Clinical relevance in regional anesthesia of the AN

A wide range of peripheral nerve blockade techniques has been used for pain relief after arthroscopic surgery (Beecroft and Coventry, 2008; Fredrickson *et al*., 2010). The interscalene nerve blockade (ISB) is the most common approach (Winnie *et al*., 1970, Fredrickson *et al*., 2010; Abdallah *et al*., 2015). This highly effective procedure is not suitable for patients with severe pulmonary disease, particularly for those with restrictive conditions (Verelst and van Zundert, 2013). A combined, US-guided SSN and AN blockade has been proposed as an alternative procedure that would avoid respiratory complications and upper limb paralysis (Price, 2007; Price, 2016; Price, 2017).

The main source of innervation to the shoulder joint is the SSN, with the AN supplying around 30% (Aszmann *et al.*, 2012). However, blocking these two nerves alone might not give adequate pain relief since the lateral pectoral (LPN) and musculocutaneous (MCN) nerves also contribute to joint innervation (Wrete, 1949; Aszmann *et al.*, 1996). Along its course, the AN can be subdivided into two segments: the first between the root of the nerve and the inferolateral edge of the SSM, and the second (distal segment) between the inferolateral border of the SSM and the final branching of the AN, which is a mean distance of 1.1 cm caudal to the emergence of the AN from the posterior cord (Fig. 1). This pattern is found in 86.7% of cases (Uz *et al*., 2007). Other authors propose alternative subdivisions that similarly define a first segment closely related to the SSM (Duparc *et al*., 1997; Tubbs *et al*., 2001) (Fig. 1A). In many cases, the nerve branch innervating the shoulder joint (called the joint nerve – JN - by some authors) arises directly from the main nerve in the first segment adjacent to the SSM (Duparc *et al*., 1997). This pattern, with early detachment of the JN from the AN, could imply that a posterior injection approach, like the one usually employed for the AN blockade (Rothe *et al*., 2011; Pitombo *et al*., 2013; Dhir *et al*., 2016; Neuts *et al*., 2018), reaches the AN after fibers directed toward the articular capsule leave the main nerve, which would result in incomplete anesthesia. In fact, failure rates for posterior blockades have been reported to be as high as 41.4% (Dhir *et al*., 2016).

In this context, we decided to study an anterior, US-guided approach for the AN blockade. Using Thiel-embalmed cadavers, we compared the spread of dye along the AN after anterior and posterior US-guided approaches. Using formalin-fixed cadavers, we studied whether the detachment pattern of the JN and/or any other articular branch from the main AN trunk could provide good anatomical support for the application of an AN anterior blockade.

Materials and methods

To simulate an AN blockade we used six Thiel-embalmed cadavers from the Department of Anatomy, Histology and Neuroscience of the Universidad Autónoma de Madrid. The bodies used for this study were donated for scientific and teaching purposes in accordance with Spanish law; the study was approved by the University Ethics Committee and conducted respecting ethical guidelines. Anterior and posterior approaches were performed on all cadavers with arbitrary choice of side for each technique.

The procedures were performed using a high frequency (13 Hz) 6 cm linear US transducer (SonoSite ® Xporte). For the anterior approach (Fig. 2; Fig. 3 A, C), the arm was in an externally-rotated and extended position. The transducer was placed on the anterior (Fig. 3 A, C) aspect of the shoulder joint and a 21G Contiplex ® needle was inserted in the selected plane, between the deep deltoid fascia (*fascia deltoidea*) and the superficial fascia of the SSM (SSF) (Fig. 3, D). The insertion was made using the acromion as a surface reference, as illustrated in Fig. 2. Needle position was confirmed by observing the course of the needle along the selected plane. After confirmation of appropriate needle placement, 15 ml of 0.5% methylene blue (MB) was manually injected, using live Doppler imaging to follow the dye release (Fig. 3 E, F). The posterior approach was performed with the cadaver placed laterally with the elbow lightly flexed in order to achieve a neutral position. Using the tip of the acromion as a reference, the probe was placed parallel to the longitudinal axis of the arm and medially to the surgical neck of the humeral head (approximately 2 cm below the acromion). At the point where the AN enters the quadrangular space, an anechoic gap appears around the surgical neck, under the deltoid muscle. MB dye (0.5%, 15 ml) was injected after confirming needle position.

Twenty-one other formalin-fixed cadavers were dissected bilaterally to exmine JN branching from the AN. Once the posterior cord of the brachial plexus and the emergence of the AN had been identified by an experienced anatomist, photographs were taken to document the course of the nerve between the point where the AN emerged from the posterior cord and the first appearance of an articular branch. The distance between the point where the AN exited the posterior cord and the inferolateral border of the SSM was measured. All epidemiological data for the cadavers used in this study are shown in Table 1.

The anterior region of each cadaver was dissected in detail. The initial incision ran along the skin covering the deltopectoral triangle in all cadavers. After the pectoral muscles were exposed, the *pectoralis major* and *pectoralis minor* were partially detached from their upper insertions to reveal the coracoid process, which was used as a reference to start minute dissections of the fatty compartment around the SSM. Next, the upper and medial border of the *coracobrachialis* and the *biceps brachii*, and the remaining nerves in the axillary region, were carefully dissected. A single incision was made from the coracoid process to the distal third of the posterior midline of the arm in all cadavers to examine the quadrangular space.

Results

US-guided approach to the first portion of the AN

In the externally rotated and extended arm position, the SSM was pulled rostrally and lay in an easily identifiable area under the deep lamina of the deltoid fascia (Fig. 3 B, D for comparisons between US patterns). The external rotation created a space in which the *coracobrachialis* (CB) and the *biceps brachii* (BB) muscles were separated and the only possible structure between the deep lamina of the deltoid fascia and the superficial lamina of the SSM fascia was the first portion of the AN itself. The myotendinous nature of the lateral insertion of the SSM produced mixed echogenicity (Fig. 3D), resulting in a somewhat dotted pattern that made the SSM and the overlying fascial lamina straightforward to identify. The methylene blue dye injected into this space (Fig. 4) spread along the whole area overlying the SSM (Fig. 4E, F) and around the proximal insertions of the CB and BB (Fig. 4C,D), thus involving the muscular branches of the MCN (Fig. 4A, B). The anterolateral aspect of the shoulder joint and the intraarticular course of the BB tendon were also heavily stained (Fig. 4C, D). In contrast, when injections were performed using posterior approaches, the staining was limited to the quadrangular space and reached neither the anterolateral aspect of the joint nor the proximal insertions of the CB and BB (Fig. 4G, H). The interpectoral space where the LPN lies was not stained in any of the cases, independently of the approach.

The branching of the AN

Dissection was not completed in two of the formalin-embalmed cadavers (one shoulder each) because of artefacts in the tissue.

In all cadavers examined in this study, the AN was rooted in the posterior cord of the brachial plexus and followed an angular course over the anterior aspect of the SSM up to the inferolateral border of the muscle, where the AN abruptly bent dorsally to reach the quadrangular space. The nerve attachment to the anterior aspect of the SSM resulted in a constant relationship between the AN and the deltoid fascia.

The branching pattern of the AN and the emergence of the joint nerves were analyzed, with special attention to the branching of the main nerve and the emergence, if this occurred, of the articular nerves in the first portion of the AN. According to this criterion, two main primary patterns were identified in the AN: (a) no branching in the first portion (Fig. 5 A, G) and (b) branching in the first portion (bi- or tri-furcated) without identifiable small articular branches (Fig. 5B, C and I). Eleven specimens (See Table 2) also showed early emergence of small articular branches from the main trunk at any point along the first portion, irrespective of the behavior of the main trunk (Fig. 5D-F, H). This latter pattern was extremely variable, the JN arising either as a single trunk well before the inferolateral border of the SSM or as multiple small nerves over the course of the main nerve. The articular nerves could also emerge from either the ventral or the dorsal aspect of the AN. In two cases, the articular nerves emerged from the dorsal aspect of either the AN bifurcation itself or from the dorsal aspect of the posterior AN branch (Fig. 5F).

We describe two patterns of AN branching. The primary pattern refers to the division of the AN into anterior and posterior branches. In our population, 62.5% of specimens showed the same pattern, with no branching in the first portion of the AN (Fig. 5A). The remaining shoulders showed either a primary bifurcation (17.5%) or secondary branches (20%) emerging in the first portion of the AN (Fig. 5B, C and Table 2).

Secondary patterns were restricted to cases in which small, narrow nerves directed to the joint emerged from the main trunk (independently of the primary pattern) and ran ventrally to the myotendinous anterolateral aspect of the SSM (see Fig 5D-F and Table II). These branches were present in 27.5% of cases. Furthermore, in three cases, a small articular branch lay beside a single trunk that provided no other branch proximally to the inferolateral border of the SSM. Globally, 45% of shoulders showed an innervation of the joint that, to some degree, emerged well before the AN left the anterior aspect of the axilla and entered the quadrangular space.

Discussion

Our cadaveric study demonstrates how the US-guided anterior approach to the AN that we describe reaches the main branches of this nerve more reliably (as well as other nerves that are important for shoulder joint innervation) than does the classical posterior approach. Most studies investigating the AN deal with the course of the nerve in relation to the deltoid muscle (Loukas *et al.*, 2009) or with the distribution of its distal branches in the shoulder joint and the surrounding muscles and skin (Apaydin *et al.*, 2009). In a recent cadaveric study, Feigl *et al*. reported an anterior approach to the blockade of the AN and intercostobrachial nerve in the axillary fossa (Feigl *et al*., 2018). They identified the AN in the quadrangular space in 99% of cases and demonstrated the feasibility of an anterior approach. However, orientation inside the axillary fossa and the anatomical landmarks they provided could be challenging, while a more lateral approach like the one described here seems more straightforward. To our knowledge, this is the first anatomical study to describe the behavior of the AN in the anterior aspect of the shoulder joint, i.e., in the area that could be reachable from an anterior approach when attempts are made to anesthetize the shoulder joint capsule.

As we show in Table 2, there is a wide range of inter- and intra-individual variations. Therefore, a technique that makes it possible to block the first portion of the AN (where it maintains a constant anatomical relationship with the SSM) increases the reproducibility of the procedure. Higher reproducibility with a higher success ratio for an AN blockade (see below, Dhir *et al*., 2016) would allow the AN blockade, either alone or in combination with an SSN blockade, to become a minimally invasive alternative for anesthesia in shoulder joint surgery and, particularly, to be an excellent technique for post-surgical pain control or chronic pain management.

Combined SSN and AN blockades are the main alternatives in cases when ISB is contraindicated. Most contraindications arise from concomitant ipsilateral phrenic nerve palsy linked to the injection of drugs into the interscalene space (Urmey and McDonald, 1992; Kessler *et al*., 2008; Bergmann *et al*., 2016). Thus, ISB is not suitable for patients with chronic respiratory diseases such as chronic obstructive pulmonary disease or diffuse parenchymal lung disease (see Introduction, Verelst and van Zundert, 2013). Multiple studies have reported a wide range of outcomes of the combined approach (Price *et al*., 2012; Pitombo *et al*., 2013; Dhir *et al*., 2016; Neuts *et al*., 2018). Early stage analgesic success seems to be lower for this technique than for ISB (Pitombo *et al*., 2013; Dhir *et al*., 2016; Neuts *et al*., 2018). Moreover, most of these studies show incomplete blockade of both SSN and AN, a percentage that can rise to 41.4% (Dhir *et al*., 2016) even in US-guided procedures (Price *et al*., 2017). We hypothesize that this high failure rate is due to incomplete blockade of the joint branches arising from the SSN, LPN and MCN when the usual posterior approach is used (Wrete, 1949; Aszmann *et al*., 1996). Neither the LPN nor the MCN is reachable through the quadrangular space (Velpeau triangle), while in around one third of the population the JN (or articular branches) emerges from the AN branches before the AN reaches the most posterior aspect of the quadrangular space (Fig. 5) (Duparc*et al*., 1997), as we show in our dissections of formalin-embalmed cadavers. However, as described in previous reports, the first segment of the AN follows a course in close contact with the SSM (Duparc *et al*., 1997). Moreover, the position of the AN changes significantly between medial and lateral rotations of the arm (Fox *et al.*, 2019). The therapeutic approach to this segment can be facilitated when the patient´s arm lies in an extended and externally rotated position; therefore, we have used the more realistic Thiel-embalmed models here to describe the anatomical landmarks for reaching this region. Not only does injection into this space following the landmarks allow a wide yet controlled distribution of the injected substance throughout the anterior aspect of the shoulder joint, but it also provides a collateral diffusion that heavily involves the inferomedial aspect of the long head of the BB as well as the intraarticular segment of its insertion tendon. This diffusion pattern, if produced by an analgesic drug, could create a comprehensive analgesic effect that would involve not only the joint branches (arising either from the first segment of the AN or more distally) but also the MCN branches that directly or indirectly (through the innervation of BB) provide sensitive innervation to the shoulder joint. This collateral blockade of the BB could also preclude the potential contribution of reflex spasms from the periarticular musculature to articular pain. It is important to remark that a complete AN blockade could provide anesthesia to the anteroinferior and lateral edges of the shoulder joint capsule (the areas of the shoulder joint that receive their nerve supply from the joint branches of the AN) and to part of the posterior aspect of the shoulder joint capsule, where small, terminal branches of the AN also provided innervation in all our specimens. This latter finding agrees with previous reports (Eckmann *et al.*, 2017). The cadaveric study of Eckmann and colleagues in 2017 is of great interest because, even if it does not deal with potential articular branches arising proximal to the quadrangular space, it provides a definition of safety zones for AN manipulation that matches the areas into which MB was injected in the present study. The remaining shoulder joint areas are innervated by the SSN, which must be blocked in combination with the AN if complete anesthesia of the shoulder is to be achieved (see Aszmann *et al.*, 1996 for the shoulder innervation and Price, 2016 for the clinical basis of the combined approach). The lateral pectoral nerve (LPN), which lies in the interpectoral space (Blanco, 2011), contributes to the innervation of both the shoulder joint capsule and the acromioclavicular joint (Wrete, 1949; Aszmann *et al.*, 1996; Tran *et al.*, 2019). The injection of anesthetic drugs into the interpectoral space, called the Pecks blockade, is a safe technique for pain control in breast surgery and some of its variants can reach the LPN with minimal involvement of other nerves (Blanco, 2011;

Pérez *et al*., 2013; Versyck *et al*., 2019). Therefore, a triple approach (AN, SSN and LPN) could be used when combined AN and SSN block is not enough to provide full pain relief.

Although generally safe, these injections can produce vascular or neural injuries. Those risks can be avoided by using Doppler ultrasonography to identify the pulsatile axillary artery and, provided that the injection is delivered between the deltoid fascia and the SSM, there is little chance of an intraneural injection. Combining Doppler identification of vascular structures with neurostimulation for nerve identification should provide an excellent safety margin, as described for other upper limb blockades (Hadzic *et al*., 2008; Gili *et al*., 2019)

This study has some limitations. The sample of Thiel-embalmed cadavers was too small to describe a coherent pattern of MB staining with both anterior and posterior approaches, even though our data suggest that the anterior approach allows a wider area to be stained. In addition, the comparability between data obtained from formalin-embalmed cadavers and data obtained from Thiel-embalmed cadavers is, at best, a matter of discussion. However, our description of the anatomical landmarks for an alternative ultrasonography-guided approach to the AN blockade could provide the basis for a clinical trial designed to assess the true clinical efficacy of this new approach. Before a large clinical trial, our proposed technique should be evaluated by smaller *in-vivo* anatomical studies to identify the safety zone better, as in the development of other upper-limb blockades (Gili *et al.,* 2019). Also, a common shortcoming of purely morphological studies is their inability to discern the true nature of macroscopically-identified fibers (either nociceptive fibers or afferent fibers related, e.g., to proprioception). This issue could be solved in further studies using immunohistochemical staining (AChE, substance P, TRPV) and/or ultrastructural imaging.

Conclusions

We describe the ultrasonographic anatomy of the shoulder anterior aspect in an extended and externally rotated arm position to assess the possibility that an anterior approach to the AN blockade could potentially provide a better analgesic outcome in clinical practice.

Around 45% of shoulders were innervated by joint nerves or small articular nerve branches arising in the first portion of the AN, at the anterior aspect of the SSM.

The AN can be approached from an anterior position provided there is a prior external rotation and extension of the shoulder, which allows the drug to be injected proximal to the branching of the shoulder articular branches. Blocking the AN using an anterior approach can allow the drug to reach the articular branches irrespective of the point of origin of the AN, and to block the MCN as well. Therefore, this approach can potentially provide better analgesia of the shoulder joint than the presently used posterior approach.

Author contributions

EGA reviewed the literature, wrote the manuscript and performed dissections; MFP conceived the idea, performed the injections and performed dissections (both authors equally contributed to this work); LJS collaborated in the analysis of the results and made the figures; JAA and UE helped in the conception of the paper and reviewed it critically; SBP, LVV, CHSZ, DGS critically reviewed the paper and took part in the dissections. All authors approved the final version of the manuscript.

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Conflict of interest

Authors declare no conflict of interest.

FIGURE LEGENDS

Fig. 1: Canonical distribution of the AN in both anterior [A] and posterior [B] aspects of the shoulder and [C] innervation of the anterior aspect of the articular capsule (modified from Wrete, 1949). In the anterior view, the DM has been faded in order to show the space under the deep deltoid fascia, while in the posterior view it has been eliminated. 1: cutaneous branches to the skin in the inferior deltoid area (anterior division); 2: muscular branches (anterior division); 3: articular branches (posterior division); 4: articular branches from the AN; 5: articular branches from the MCN; 6: articular branches from the subscapular nerve; 7: articular branches from the suprascapular nerve. AN: axillary nerve; BB: *biceps brachii* muscle; CB: *coracobrachialis* muscle; CHP: posterior humeral circumflex artery; IS: *infraspinatus* muscle; MCN: musculocutaneous nerve; RN: radial nerve; SSM: *subscapularis* muscle; TMA: *teres major* muscle; TMI: *teres minor* muscle.

Fig. 2: Schematic drawing of the proposed anterior approach using the acromion (*) as a surface reference. The needle is inserted immediately caudal to the acromion (*) in a cephalic to caudal direction. The appropriate angle between the needle and the skin beneath the tip of the acromion can differ among individuals but is always <40º and usually <15º. Using this approach, the plane between the deltoid fascia and the SSF lies 4-4.5 cm deep in 100% of the cases studied.

Fig. 3: Ultrasonographical anatomy of the anterior area of the shoulder joint before extending and externally rotating the arm [A]. The US pattern of this position [B] shows the humeral head (H) covered by the deltoid muscle (DM); the musculotendinous insertions of the SSM are barely discernible from the inferior fascial tissue surrounding the DM. Extension and external rotation of the arm [C,E] pulls the lateral region of the SSM rostrally [D], providing a reference for the injection [F] between the deltoid fascia (DF) and the suprascapular fascia (SSF). The external rotation and extension of the arm facilitates localization of the AN in the ultrasonographical imaging (comparison between [B] and [D]). The injections can be checked while Doppler color imaging is performed [F] and confirmed afterwards by the swelling of the interfascial space [G+] and the suprascapular subfascial space [G, H **]. The arrowhead (B, D) marks the needle.

Fig. 4: [A-F] Methylene blue (MB) staining around the anterior area of the scapulohumeral joint. A, B: MB diffusion involving the periarticular tissue forming the floor of the anterior aspect of the shoulder, partially staining both the main trunk and the muscular branches of the MCN. [C, D]: MB diffusion around the anterolateral aspect of the left shoulder [C] showing intense involvement of the tendon of the long head of BB as it passes through the joint [D, arrow]. E, MB diffusion involving the

AN (arrow) in the transition between its first and second segments, before bending dorsally to reach the quadrangular space. F: MB distribution along the lateral aspect of the joint capsule, with strong dyeing of the AN (arrow). Both pictures also reveal partial but obvious staining of the MCN muscular branches to the BB (*) and CB (**). G-H: dissections in both the anterior [G] and posterior aspect of the shoulder [H] after a posterior approach showing no staining of the first portion of the AN (arrow).

Fig. 5: Primary [A, B, C] and secondary [D, E, F] patterns of the first portion of the AN. A: no branches; B: AN divides into anterior and posterior branches in the course of its first portion; C: higher divisions still proximal to the quadrangular space; D: multiple narrow nerves; E: a small articular nerve emerging from the superior surface of the main AN trunk; F: a single small articular nerve emerging from another surface, including the posterior aspect of the bifurcation. Dissection pictures showing the three main patterns [G-I] of AN before it passes beneath the SSM in formalin-embalmed cadavers. G: no branching before the inferolateral border of the SSM; H: early branching in the first portion, including an unspecified articular nerve (arrow). I: small articular branches (arrow) emerging during the first portion of the AN from surfaces other than the superior AN surface.

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Abbreviations

AD: Alzheimer's disease

AN: axillary nerve

BB: biceps brachii muscle

BPC: bronchopulmonary carcinoma

CB: coracobrachialis muscle

CHP: posterior humeral circumflex artery

COPD: chronic obstructive pulmonary disease

DM: deltoid muscle

DF: deltoid fascia

IS: infraspinatus muscle

ISB: interscalene nerve block

JN: joint nerve

LPN: lateral pectoral nerve

MB: methylene blue

MCN: musculocutaneous nerve

MI: myocardial infarction

MODS: multiple organ dysfunction syndrome

RN: radial nerve

SSF: suprascapular fascia

SSM: subscapularis muscle

SSN: suprascapular nerve

TMA: teres major muscle

TMI: teres minor muscle

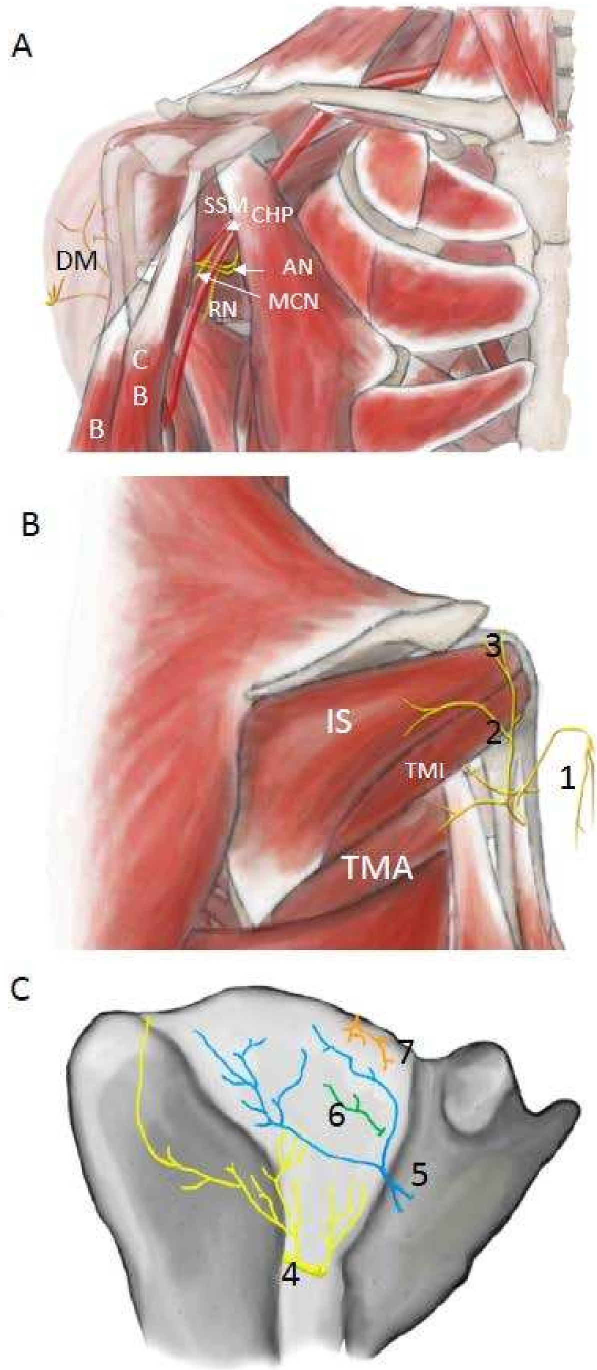
Cadaver	Sex	Age	Cause of death	Weight (kg)	Stature (m)	Post-mortem gap (hours)	Embalming solution
346	M	74	Heart failure	110	1.85	8	Thiel
332	F	73	Brain bleeding	70	1.6	27	Thiel
258	F	92	Pneumonia	100	1.7	48	Thiel
281	F	78	Septicemia	60	1.6	21	Thiel
306	F	94	MODS	100	1.6	9	Thiel
391	M	73	Heart failure	120	1.93	4	Thiel
81	M	75	Mesothelioma	85	1.8	20	Formalin
12	F	65	COPD	50	1.7	23	Formalin
58	F	95	Septicemia	50	1.5	24	Formalin
86	M	86	Septicemia	110	1.85	72	Formalin
5	F	95	Sudden death (AD)	40	1.45	34	Formalin
20	M	91	Heart failure	60	1.75	13	Formalin
83	F	65	BPC	70	1.6	14	Formalin
22	M	84	Pneumonia	110	1.8	25	Formalin
18	M	90	Pleural effusion	100	1.7	12	Formalin
57	F	96	Heart failure	50	1.55	29	Formalin
23	F	79	Pneumonia	115	1.7	67	Formalin
31	M	89	MODS	80	1.7	11	Formalin
24	F	80	MI (AD)	30	1.45	17	Formalin
33	M	76	Metastatic Breast Cancer	80	1.7	24	Formalin
25	M	89	Mesenteric infarction	80	1.6	9	Formalin
39	M	74	BPC	50	1.75	7	Formalin
40	F	96	Pneumonia	50	1.6	34	Formalin
43	F	57	Kidney failure	110	1.8	6	Formalin
30	M	91	MODS	95	1.7	8	Formalin
64	F	101	Sudden death	35	1.5	11	Formalin
52	F	106	COPD	55	1.5	14	Formalin

Table I: Epidemiological data of studied cadavers. A total amount of 27 cadavers, 12 males and 15 females were studied, six of them were Thiel embalmed and 21 of them were formalin embalmed. Mean age was 83.9 ± 12 years old. Cadavers with surgeries or obvious pathological findings in the scapulohumeral joint were discarded. Post-mortem delay before embalming varied (4 to 72 hours) depending on the source of the donations (mean time 21.9 ± 17.2 hours). Abbreviations: AD, Alzheimer's disease; BPC, bronchopulmonary carcinoma; COPD, chronic obstructive pulmonary disease; MI, myocardial infarction; MODS, multiple organ dysfunction syndrome.

Cadaver	*Shoulder*	*Primary pattern*	*Secondary pattern*
57	Left	C	None
57	Right	A	None
23	Left	B	F
23	Right	A	None
31	Left	A	None
31	Right	A	None
24	Left	C	A
24	Right	A	None
33	Left	C	None
33	Right	C	None
25	Left	A	E
25	Right	B	F
39	Right	A	None
39	Left	A	None
40	Left	C	None
40	Right	A	E
43	Left	B	None
43	Right	A	None
30	Right	A	None
30	Left	A	E
64	Right	A	None
64	Left	A	None
52	Left	A	None
52	Right	B	E
81	Right	C	None
81	Left	C	None
12	Right	C	D
12	Left	A	None
58	Left	A	None
58	Right	A	None
86	Right	A	None
86	Left	A	None
5	Left	A	None
5	Right	A	None
20	Left	A	None
83	Left	A	F
83	Right	B	None
22	Left	A	E
22	Right	B	None
18	Left	B	F

Table 2: Patterning of the AN branching during its first portion. Primary pattern refers to the division of the AN into its anterior and posterior branches during its course over the anterior aspect of the SSM. A: no branches; B: AN divides into its anterior and posterior branches during its first portion; C: further divisions still proximal to the quadrangular space. Secondary patterns are related to the presence of small articular branches in this region. D:

multiple narrow nerves; E: a single narrow nerve emerging form the upper surface of the main AN trunk; F: a single narrow nerve emerging elsewhere, including on the posterior aspect of the bifurcation. See also Fig. 5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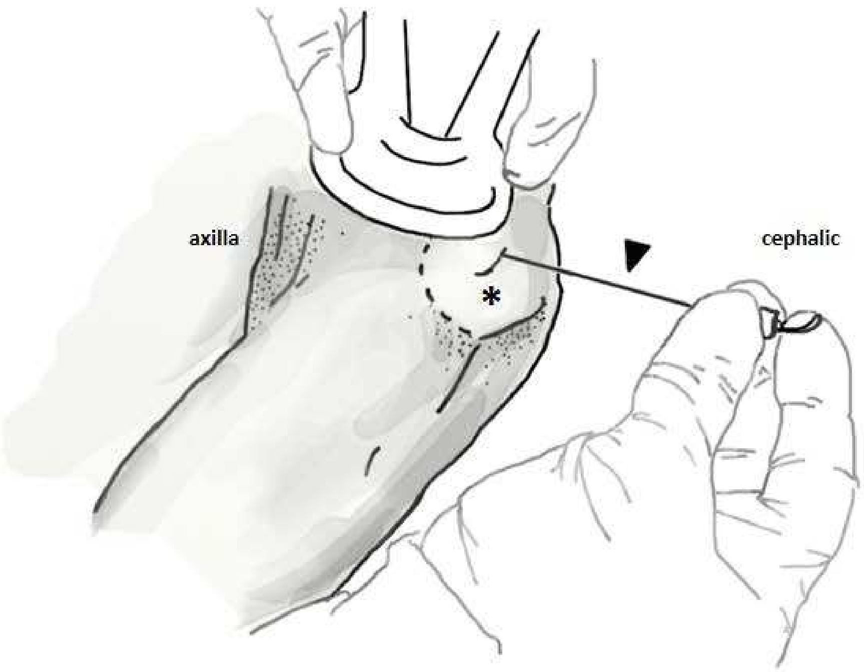
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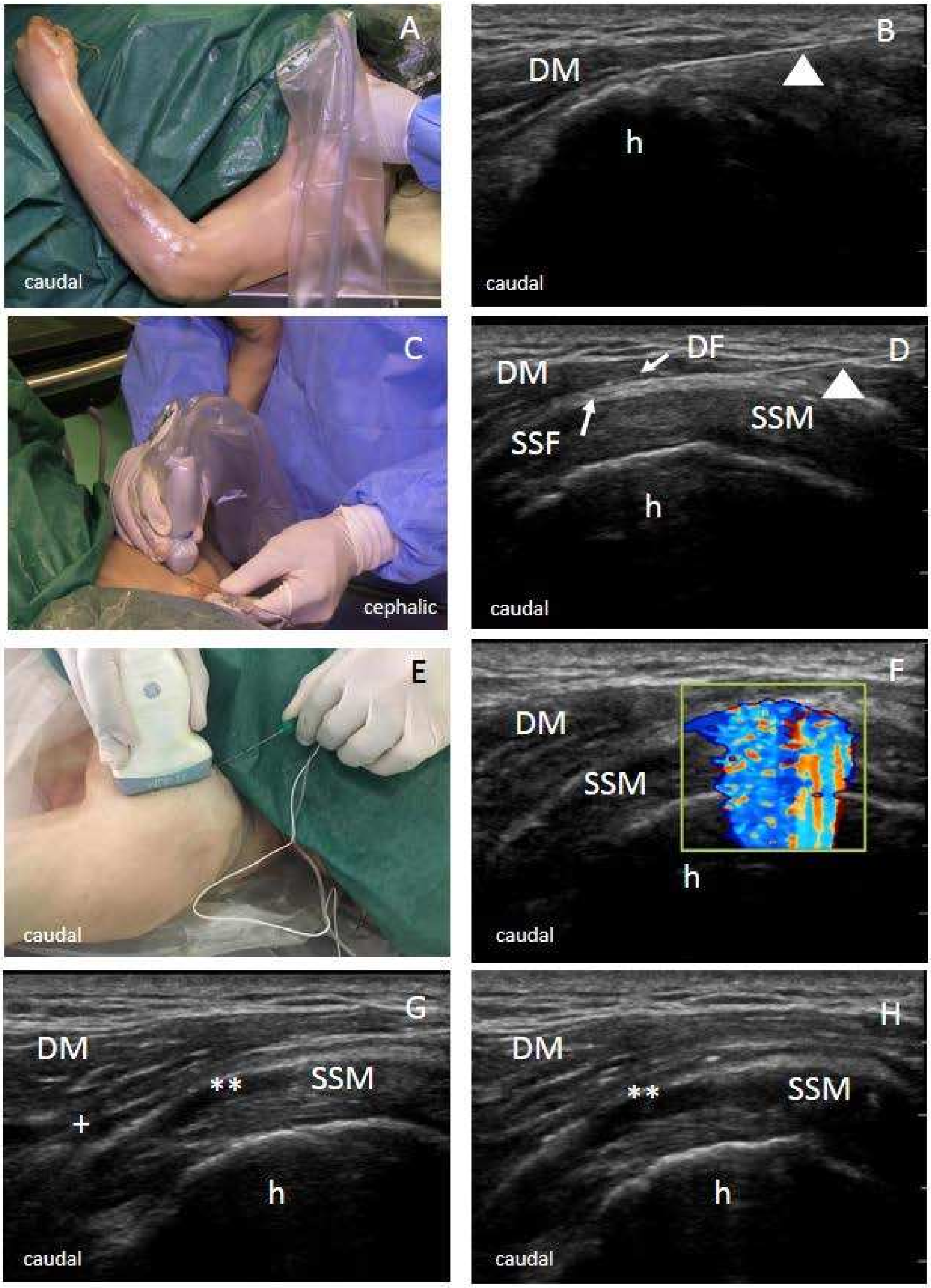
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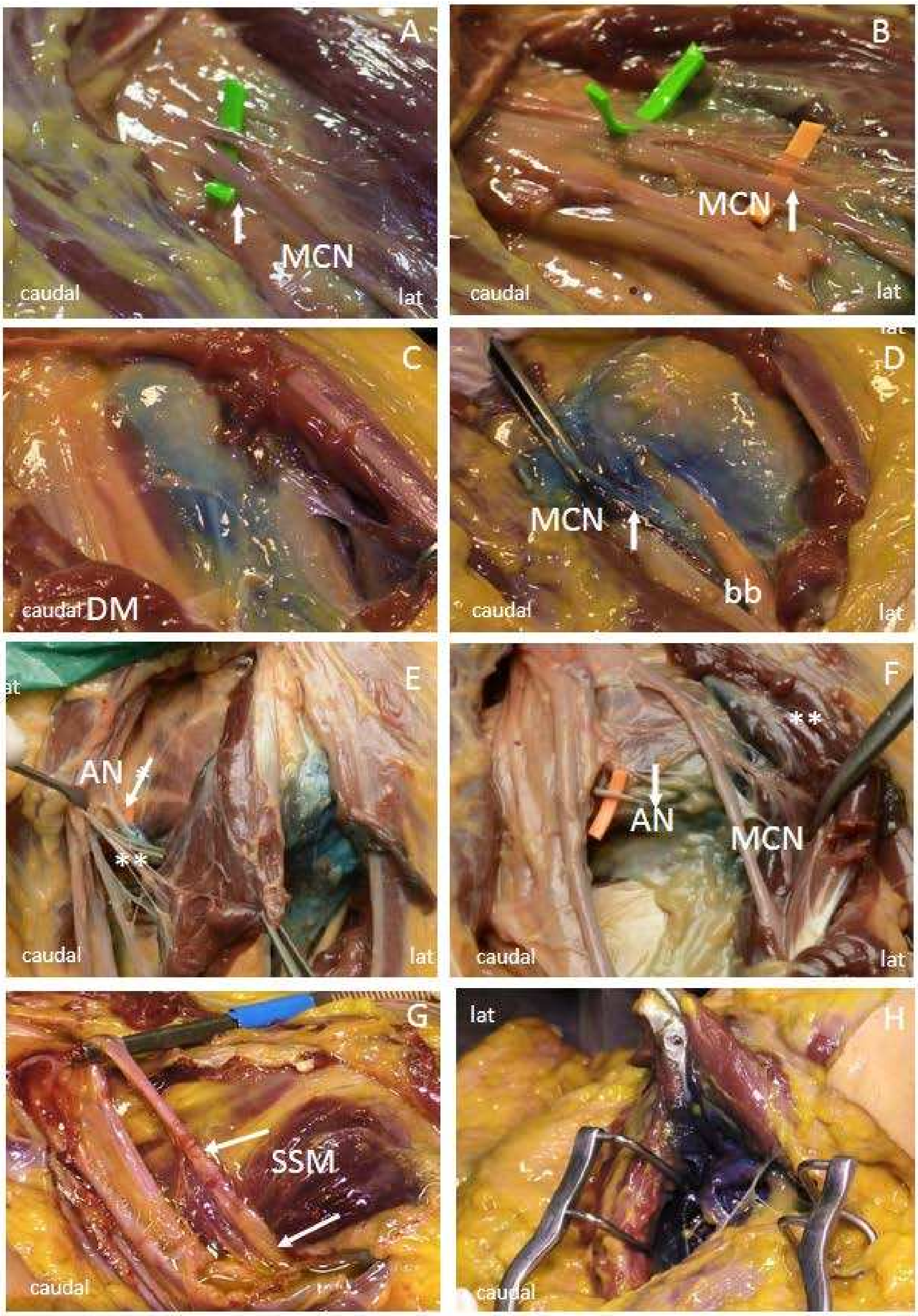
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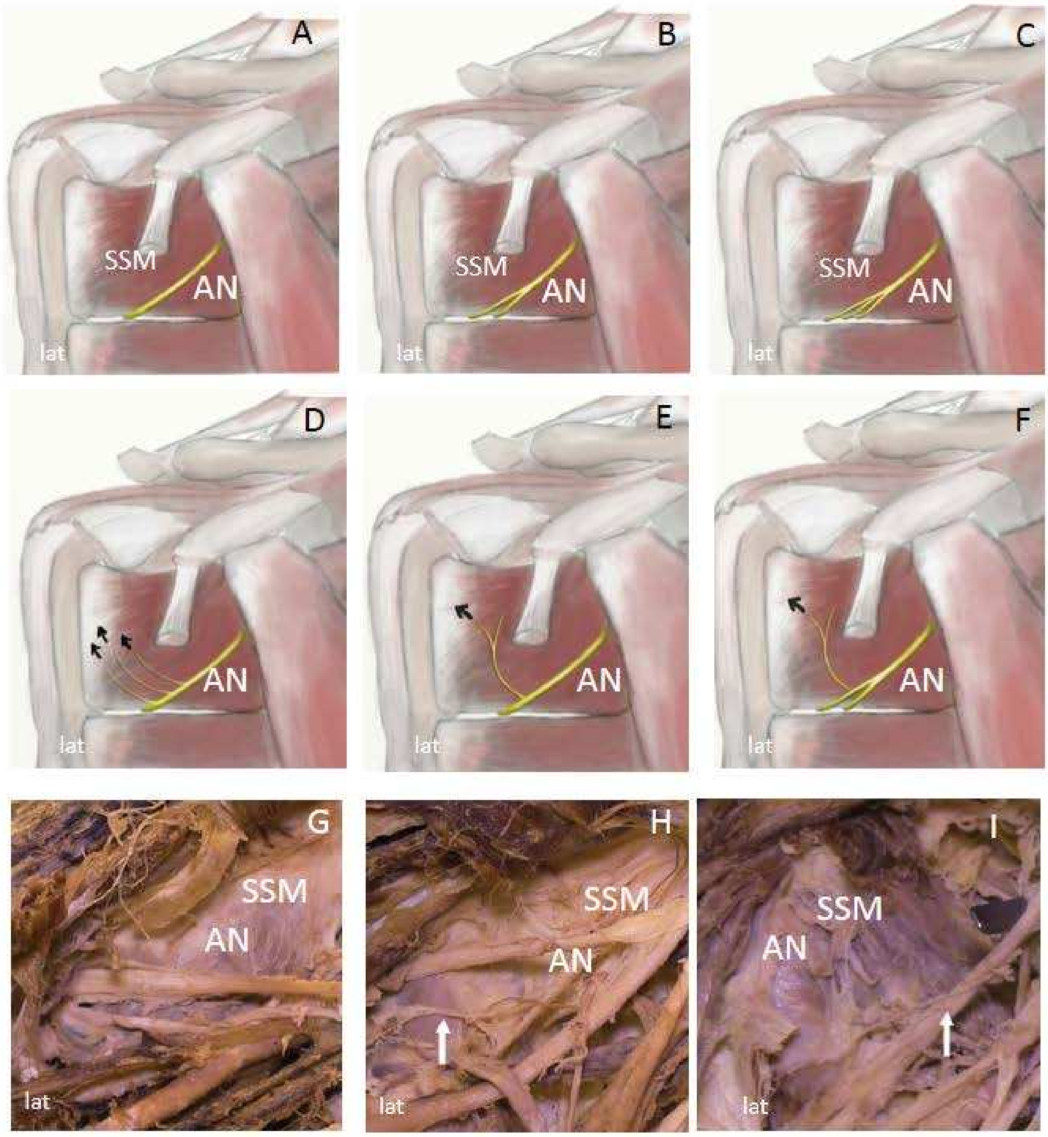
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